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Energy balance in the production of mountain coffee ☆

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ABSTRACT

Coffee culture is highly relevant in Brazilian agriculture in socioeconomic terms. The energy balance of production systems results from the subtraction of the consumed energy (MJ ha^{-1}) from the produced energy (MJ ha^{-1}), in any culture or system. Produced energy is understood as the transformation resulting from the production of grains or fruits, or dry matter, into energy. Consumed energy or cultural energy (MJ ha^{-1}) is understood as the sum of the energy coefficients related to the fertilizers, seeds, fungicides, herbicides, insecticides, incident solar energy during the cycle and operations related to sowing, fertilization, application of products and manual harvesting. Post-harvest is considered to be the sum of the energy coefficients spent in the pre-processing and processing operations used in each treatment. The present work aimed at evaluating the energy balance in a mountain coffee production system with emphasis on production, harvest and post-harvest. It was concluded that plants and their individual components take little advantage from the amount of energy aggregated in the energy balance (less than 0.3%).

Contents

1. Introduction

According to Conab [7], the Brazilian production of green coffee Arabica in the 2013 harvest was 38.28 million bags of 60 kilos.

Consumption of energy in a system of production is one of the most worrying things in agricultural activity. Accordingly, the calculation of the energy balance is one of the most important tools when you want to assess the sustainability of agroecosystems.

In terms of energy, an agricultural production system can be interpreted as a converter of solar energy into food energy, with the intervention of water, carbon dioxide and semi-manufactured products, such as fuels, fertilizers, pesticides and seeds, among others [9].

The energy balance of production systems results from subtracting the consumed energy (MJ ha^{-1}) from the produced energy (MJ ha^{-1}), in any culture or system. Produced energy is regarded as the transformation resulting from the production of grains or fruits, or dry matter into energy. The consumed energy, or cultural energy

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(MJ ha^{-1}), corresponds to the sum of the plots related to fertilizers, seeds, fungicides, herbicides, insecticides, incident solar energy during the cycle and the operations related to sowing, fertilization, application of products and harvest. Post-harvest energy is considered to be the sum of the energy coefficients spent in the pre-processing and processing operations used in each treatment.

The energy value of tractors, trucks and implements, according to Doering et al. [8], is calculated according their weight, multiplied by the energy value of the material used in their making, with the addition of 858 MJ kgf^{-1} (20.5 Mcal kgf^{-1}) for tires and 5% of the total energy for repairs and maintenance.

According to the BEN [3], Balanço Energético Nacional (National Energy Balance), the calorific Power of the fuels used for gasoline is 10.400 kcal L^{-1} and for diesel oil is 10.100 kcal L^{-1}.

Pimentel and Hall [17] used the values of 271.713, 363.805 and 418.223 kJ kg^{-1} (64.910, 86.910 and 99.910 kcal kg^{-1}) for fungicides, insecticides and herbicides, respectively.

Sartori and Basta [18] and Serra et al. [19] adopted the energy indicators from the American economy, which are: for nitrogen (N), 58.081 kJ kg^{-1} (13.875 kcal kg^{-1}); for phosphorus (P_2O_5), 6.969,6 kJ kg^{-1} (1.665 kcal kg^{-1}); for potassium (K_2O), 4.646,5 kJ kg^{-1} (1.110 kcal kg^{-1}) and for limestone, 167,4 kJ kg^{-1} (40 kcal kg^{-1}). In the fertilization with lime, Pimentel et al. [16] reported the value of 1.318,6 kJ kg^{-1} (315 kcal kg^{-1}).

To calculate the photosynthetically active radiation (PAR), it is necessary to consider that plants grow because of the radiant energy (light), photosynthesis process (visible range of radiation between 0.4–0.7 μm.) and the capacity to absorb light by the canopy.

The present work aimed at evaluating the energy balance in a mountain coffee production system. The specific goal was to evaluate: (a) the energy balance in the production stage, (b) the energy balance in the harvest stage and, (c) the energy balance in the post-harvest stage.

2. Material and methods

The experiment was carried out in an agricultural property, located at 20° 52′ latitude south, 43° 10′ longitude west and at 702 m average altitude. The climate is tropical of average altitude [13].

Inside the cultivated area of 60 ha, an experimental area of 14,25 ha was randomly selected and divided into four plots. The species cultivated was Coffea arabica, cultivar Catuaí-Vermelho, lineage MG-44, at initial age of 2.5 years, planted with the spacing of 2.5 m between lines and 0.8 m between plants. Table 1 presents the characteristics of the crop.

All the agronomical operations necessary to the coffee productive process and the different treatments for the fertilization of the plots selected were considered, according to the technical recommendations of the Empresa de Pesquisa Agropecuária do Estado de Minas Gerais (EPAMIG). The needs of phosphorus and potassium were calculated and recommended according to the remaining content of the respective soil elements, content of clay and the productivity expected in the plots evaluated.

Potassium was provided in three applications during each phenological year. The needs of nitrogen were calculated according to the remaining content of nitrogen found by the results of the leaf analyses and by the productivity expected in the period evaluated. The calculations to determine of the needs of liming and gypsum

Table 1
Characteristics of the crop and harvest procedures.

Item	Plots					
	1	2	3	4	5–13	14
Spacing (m)	2.5 × 0.8					
Number of plants	17.761	20.094	19.734	13.650	203.750	25.000
Area (ha)	3.55	4.02	3.95	2.73	40.75	5.00
Harvest in cloth	Semi-selective	Semi-selective	Semi-selective	Semi-selective	Harvesting	

Note: the population of plants, in each plot, was achieved with the collection and counting of one leaf of each plant, in the respective plots.

Table 2
Characterization of the lots of coffee, in the phenological years of 2003/2004 and 2004/2005.

Plots	Area (ha)	Number of plants	Productivity (bags ha^{-1})	
			2003/2004	2004/2005
01	3.55	17.761	29.4	36.6
02	4.02	20.094	34.4	41.3
03	3.95	19.734	30.1	39.2
04	2.73	13.650	23.2	34.2

Table 3
Energy values of machines and implements used in the production systems of mountain coffee.

Machines and implements	Manufacturer/model	Mass (kg)	Energy	
			10^3 (MJ t^{-1})	10^3 (MJ)
Tractor Number 1	Massey Ferguson—Mod. 275	3.759	[b]93.05	349.74
Tractor Number 2	New Holand—Mod. TL75E	3.500	[b]93.05	325.75
Truck	Mercedes Benz—Mod. 710P	5.300	[c]64.67	342.80
Sprayer[a]	Jacto—Mod. 2000	1.650	[b]45.21	74.64
Cart Number 1	Agric. Machinery—3.5 × 2.0 × 0.6	0.830	–	–
Cart Number 2	Agric. Machinery—4.0 × 2.0 × 0.6	0.800	–	–

Source
[a] system with ten sprinklers and a 2.000 L tank.
[b] Pimentel et al. [16]
[c] Doering et al. [8].

Table 4
Energy values inherent to inputs used in mountain coffee production systems.

Inputs	Embodied energy (MJ kg^{-1})			Average
	Pimentel	Stout	Doering	(MJ kg^{-1})
Nitrogen (NH_2)	61.59	58.66	58.14	59.46
Phosphate (P_2O_5)	12.57	16.32	6.98	11.96
Potassium (K_2O)	6.70	6.31	4.65	5.89
Limestone	–	–	0.17	0.17
Gypsum	–	–	0.18	0.18
Pesticides	306.96	–	–	306.96

Source: Pimentel [17], Stout [20] and Doering et al. [8].

Table 5
Energy values of materials and organic compounds from agricultural residues.

Organic Input	Average embodied energy ($MJ\ kg^{-1}$)		
	Literature	2003/2004	2004/2005
Organic fertilizer	–	24.2	21.4
Chicken manure	[b]12.69	12.69	12.9
Coffee straw	[a]15.5	15.5	15.5

Source
[a] Lopes et al. (2001) and
[b] Teixeira et al. (2005).

Table 6
Energy embodied in some pesticides used in the mountain coffee production process.

Pesticides	Embodied energy		
	[15]	[22]	Aggregated average energy
Fungicide:			
Propiconazole	271.97		271.97
Pyraclostrobin[a]			271.97
Carbendazim[a]			271.97
Herbicide:			
Atrazine		418.62	418.62
Glyphosate[b]	418.62		418.62
Trifluralin	364.15		364.15
Paraquat	263.01		263.01
Phosphonomethyl[b]			418.62
Insecticide:			
Lambda-cyhlothrin	364.15		364.15
Disulfoton[c]			364.15
Endosulfan[c]			364.15
Phenoxybenzyl-Dibromo-vinyl[c]			364.15
Trichlorfon	364.15		364.15

Note
[a] Fungicides employed
[b] Herbicides employed and
[c] Insecticides employed.

application, and fertilization were carried out based on the recommendations for the use of corrective products and fertilizers in Minas Gerais – 5th approximation [1].

The determination of the energy balance of coffee plants was carried out according to the method proposed by Serra et al. [19]. For the calculations of the quantitative indexes involving systems, crop yield, field operation and dry matter, data and guidelines produced by Serra et al. [19], Pimentel [15] and Freitas et al. [10] were used.

The fuel consumption of tractors and trucks was evaluated based on the time of use of the machine and the volume consumed per hour. The consumption of lubricants used in maintenance services was measured according to the amounts (kg) needed for each operation. The trucks, tractors and implements were weighed in a platform scale, with resolution of 1.0 kg, for the achievement of the respective masses, and the operation time was clocked for each activity.

The average energy contained in the plants of average size was calculated based on the measurement of the calorific value of the stems, leaves, branches, roots and fruits of four plants randomly collected.

The radiation balances were determined as proposed by Camargo and Camargo [6], in September, November, January and March of each phenological year.

The meteorological data were collected inside the plots 1–4, and the following equipments were installed at the height of 4 m above the soil: a REBS Q.7.1 net radiometer, Serial: Q03175 (calibration factor$=8.80\ W\ m^{-2}\ mV^{-1}$), to measure the net radiation (Rn); a pyranometer "of the Eppley type" model 8.48, with constant ($7.08\ mV\ cal^{-1}\ cm^{-2}\ m^{-1}$), to measure the global solar radiation (SR); a LI-COR pyranometer, model PY34820, with constant ($10\ \mu V\ W^{-1}\ m^{-2}$), to measure the reflected solar radiation (Rr) and a PAR Kipp & Zonen sensor, with sensitivity ($4.54\ \mu V\ \mu mol^{-1}\ s^{-1}\ m^{-2}$), to measure the phtosynthetically active solar radiation. The equipments were attached to an iron tube with 5 m of length, projecting it far from the mast and allowing the target to be between the inter row and the rank, favoring a good sampling of the coffee plantation. The sensors were connected to a system of LR data acquisition, with an LR-7018 analog module with eight channels, with the precision of 0.1%, connected to a computer.

Monthly supervisions were performed to control pests, in compliance with the "Pest Management" system. Disease control

Table 7
Energy consumption ($MJ\ kg^{-1}$) in the first phenological year of the coffee culture, in each plot.

Variables	Energy consumption by plots (MJ)							
	01		02		03		04	
	Energy	%	Energy	%	Energy	%	Energy	%
Soil sampling	2.887,14	0.0350	4.685,64	0.0051	4.354,56	0.0084	2.87,76	0.0046
Application of fertilizers	140.735,59	0.1720	177.658,20	0.1270	114.038,88	0.1253	106.919,69	0.1699
Correction of soil acidity	3.152,73	0.0039	4.656,0	0.0050	4.013,59	0.0044	2.930,67	0.0047
Organic fertilizer	436.629,60	0.5335	493.982,62	0.5330	483.402,80	0.5311	333.965,20	0.5307
Weed control	17.765,84	0.0217	26.060,58	0.0281	18.175,56	0.0200	12.749,20	0.0203
Pest control	124.472,80	0.1521	157.357,82	0.1698	130.201,73	0.1431	91.334,65	0.1451
Disease control	17.227,19	0.0211	27.498,39	0.0297	17.517,49	0.0192	11.817,41	0.0188
Leaf fertilization	14.388,16	0.0176	21.505,92	0.0232	16.740,00	0.0184	9.126,16	0.0145
Pruning and thinning	9.128,96	0.0112	14.013,60	0.0151	14.070,84	0.0155	9.316,96	0.0148
Squaring	6.837,12	0.0048	7.499,36	0.0081	5.351,38	0.0059	4.715,72	0.0075
Radiation balance	81.010.290,00	98.9886	91.735.596,00	98.9817	90.138210,00	99.0394	62.298.054,00	98.9923
Harvest	8.218,54	0.0100	12.282,00	0.0133	9.847,38	0.0108	6.858,63	0.0109
Pre-processing and processing	3.760,95	0.0046	5.278,91	0.0057	4.044,49	0.0044	2.862,07	0.0045
Drying	41.779,12	0.0511	50.343,64	0.0543	51.689,05	0.0568	38.298,66	0.0690
Processing	698.24	0.0009	919.16	0.0010	792.01	0.0009	422.41	0.0007
TOTAL	81.837.971,99	100.0	92.679.337,84	100.0	91.012.449,76	100.0	62.932.249,02	100.0
Total ($MJ\ ha^{-1}$)	23.052.949,86		23.054.561,65		23.041.126,52		23.052.105,87	
Total ($MJ\ sc^{-1}$)	784.113,94		670.109,75		765.485,93		993.625,25	

Table 8
Energy consumption (MJ kg^{-1}) corresponding to the second phenological year of the coffee crop, in each plot.

Variables	Energy consumption per plot (MJ)							
	01		02		03		04	
	Energy	%	Energy	%	Energy	%	Energy	%
Soil sampling	3.081,30	0.0036	2.902,47	0.0030	4.013,94	0.0042	3.090,84	0.0046
Application of fertilizers	125.787,69	0.1450	160.059,13	0.1629	158.333,62	0.1640	140.355,72	0.2103
Correction of soil acidity	3.041,28	0.0035	5.700,68	0.0058	4.107,46	0.0043	3.891,90	0.0060
Organic fertilizer	434.964,64	0.5014	491.447,02	0.5001	483.847,66	0.5012	334.429,14	0.5010
Weed control	14.170,43	0.0163	22.892,33	0.0233	19.055,23	0.0197	14.385,60	0.0216
Pest control	118.720,59	0.1369	153.600,84	0.1563	141.730,92	0.1468	99.576,06	0.1492
Disease control	12.927,21	0.0149	24.522,03	0.0250	18.841,82	0.0195	12.148,04	0.0182
Leaf fertilization	10.206,68	0.0188	18.233,24	0.0186	12.021,27	0.0125	10.537,06	0.0158
Pruning and thinning	9.565,00	0.0110	12.453,58	0.0127	11.262,10	0.0117	10.416,56	0.0156
Squaring	4.811,12	0.0055	7.982,38	0.0081	5.043,09	0.0052	5.557,76	0.0830
Radiation balance	85.856.395,00	98.9739	97.223.298,00	98.9301	95.530.355,00	98.9577	66.024.777,00	98.9192
Harvest	11.459,31	0.0132	15.654,04	0.0159	14.707,52	0.0152	12.323,54	0.0158
Pre-processing and processing	5.529,37	0.0064	6.234,16	0.0063	5.436,65	0.0056	3.962,02	0.0059
Drying	135.011,02	0.1556	128.708,26	0.3110	126.801,62	0.1314	69.981,99	0.1048
Processing	866.36	0.0010	1.099,11	0.0011	1.024,76	0.0011	623.90	0.0090
TOTAL	86.746.536,00	100.00	98.274.787,00	100.00	96.536.582	100.00	66.746147,12	100.00
Total (MJ ha^{-1})	24.435.643,94		24.446.464,49		24.439.641,18		24.449.138,14	
Total (MJ sc^{-1})	667.640,54		591.924,08		623.460,23		714.887,08	

Table 9
Relation between the energy produced by coffee plants in the first phenological year and the percentage of use by the plant.

Plot	Number of plants	Constituent part	Calorific power (MJ/kg)	Average mass (kg/Plant)	Produced energy (MJ)	Used (%)
1	17.761	Root	15.21 ± 0.23	2.7	729.390,987	0.89
	17.761	Stalk	15.62 ± 0.18	1.8	499.368,276	0.61
	17.761	Branches	14.75 ± 0.17	1.9	497.752,025	0.61
	17.761	Leaves	13.29 ± 0.15	1.1	259.648,059	0.32
	17.761	Fruits	0.00341	0.546	33.068	0.00004
Sub-total					1.986.192,415	2.43
2	20.094	Root	13.41 ± 012	2.4	646.705,296	0.70
	20.094	Stalk	16.12 ± 0.04	1.6	518.264,448	0.56
	20.094	Branches	11.24 ± 0.13	1.4	316.199,184	0.34
	20.094	Leaves	10.87 ± 0.16	1.2	262.106,136	0.28
	20.094	Fruits	0.00326	0.562	36.814	0.00004
Sub-total					1.743311878	1.88
3	19.734	Root	16.25 ± 0.11	2.3	737.558250	0.81
	19.734	Stalk	15.95 ± 0.22	1.7	535.087,410	0.59
	19.734	Branches	13.14 ± 0.13	1.9	492.679,044	0.54
	19.734	Leaves	12.74 ± 0.14	1.2	301.693,392	0.33
	19.734	Fruits	0.00333	0.529	34.763	0.00004
Sub-total					2.069052859	2.27
4	13.650	Root	10.24 ± 0.18	1.9	265.574,400	0.42
	13.650	Stalk	11,14 ± 0.15	1.4	212.885,400	0.34
	13.650	Branches	12.15 ± 0.17	1.5	248.771,250	0.39
	13.650	Leaves	13.29 ± 0.25	1.1	199.549,350	0.32
	13.650	Fruits	0.00314	0.519	22.245	0.000035
Sub-total					926.802,645	1.47

was carried out based on visual monitoring, according to the "Controlled Disease Management" system. Weed control was performed by means of manual weeding and herbicide applications.

The harvest, carried out by the semi-selective harvest in cloth method, started when the amount of green fruits in the plant was lower than 20%. The fruits received from the crop were washed in a mechanical washer with capacity of 8.0 $m^3\ h^{-1}$, which separated the heavy fruits from the light fruits. The heavy fruits (cherry, verdoengo and green) were pulped, while the green ones were discarded during pulping. The pulped fruits were mechanically desmucilated, before drying.

The method proposed by Bakker-Arkema et al. [2] was adopted to evaluate the drying system, with adaptations for the experimental conditions.

The drying stage was defined based on three treatments:

T1 – Complete drying in concrete ground. The coffee was spread in thin layers, with a maximum thickness of 0.03 m, and stirred continuously during the day, until the grains reached the water content of 11,5–12% (b.u.).

T2 – Complete drying in fixed-bed dryer, in beds (hybrid dryer). The temperature of the drying air was 43.0 ± 2,5 °C and the grains were stirred at 2-h intervals until they reached the humidity of 12 ± 0.5% (b.u.). The drying air flow was 58 ± 1.7 m3 min^{-1}, the engine power was 3.68 kW (5 cv) and the air heating system was performed by indirect firing, with burning of firewood (PCI = 13.813,8 kJ kg^{-1} and Me = 380.8 kg m^{-3} with 25% (b.u.).

T3 – Partial drying, performed in a fixed-bed dryer, in beds, up to 25–30% (b.u.) and complementation of the drying up to 12–13% (b.u.), performed in masonry drying silos. At the pre-drying stage,

Table 10
Relation between the energy produced by coffee plants in the second phenological year and the percentage of use by the plant.

Plot	Number of plants	Constituent Part	Calorific power (MJ/kg)	Average mass (kg/plant)	Produced energy (MJ)	Used (%)
1	17.760	Root	19.11 ± 0.22	2.8	950.302,080	0.84
	17.760	Caule	17.56 ± 0.18	1.9	592.544,640	0.58
	17.760	Ramos	16.17 ± 0.12	1.9	545.640,480	057
	17.760	Folhas	15.21 ± 0.14	1.3	351.168,480	0.30
	17.760	Fruits	0.00353	0.575	36.048	0.000038
Sub-total					2.439691728	2.30
2	20.093	Root	14.23 ± 0.15	2.5	714.808,475	0.73
	20.093	Caule	16.87 ± 0.08	1.7	576.247,147	0.59
	20.093	Ramos	12.25 ± 0.18	1.4	344.594,950	0.35
	20.093	Folhas	12.34 ± 0.16	1.3	322.331,906	0.33
	20.093	Fruits	0.00344	0.570	39398	0.000040
Sub-total					1.958.021,876	1.99
3	19.733	Root	14.25 ± 0.14	2.5	702.988,25	0.73
	19.733	Caule	17.57 ± 0.11	1.8	624.075,858	0.65
	19.733	Ramos	13.24 ± 0.23	1.8	470.276,856	0.49
	19.733	Folhas	10.42 ± 0.14	1.3	267.303,218	0.28
	19.733	Fruits	0.00364	0.575	41.301	0.000043
Sub-total					2.064.685,483	2.1407
4	13.649	Root	12.58 ± 0.09	1.8	309.067,956	0.46
	13.649	Caule	13.58 ± 0.17	1.3	240.959,446	0.36
	13.649	Ramos	12.19 ± 0.17	1.7	282.848,227	0.42
	13.649	Folhas	13.01 ± 0.15	1.3	230.845,537	0.35
	13.649	Fruits	0.00391	0.558	29.779	0.000045
Sub-total					1.063750945	1.59

the conditions of the treatment 2 were adopted. In the complementation of the drying, up to $12 \pm 0.5\%$ (b.u.), two silos were used, both with ventilation system, using air at room temperature. The ventilation system was turned on when the ambient air temperature varied between 20 and 27 °C, and the relative humidity varied between 55% and 70%. The silos, with capacity of 51.3 m^3, were loaded by successive layers, with thickness of 0.4 m. The water content of the first layer was 25% (b.u.) and of the superior layer (last layer), 18% b.u. The simulation model proposed by Hukill [11] was used to calculate the reduction levels in the water content, per layer, during the loading of the silos.

The samplings and determination of the water content complied with the recommendations of the Brasil [4].

The monitoring of temperature and ambient relative humidity, temperatures of the drying air, exhaustion and grains was carried out by means of an LR COM automatic system of data acquisition, model LR – 7018. The quality of the dried coffee was evaluated according to the Regulamento Técnico de Identidade e de Qualidade para a Classificação do Café Beneficiado Cru (Technical Regulation of Identity and Quality for the Classification of Raw Green Coffee) [5].

3. Results and discussion

Table 2 presents the characteristics of the experimental plots, randomly chosen, in the phenological years of 2003/2004 and 2004/2005.

Table 3 lists the equipments used for agricultural practices available in the rural property, with their respective energy values, according to Pimentel [16] and Doering et al. [8]. Table 4 presents the energy values of the inputs. Table 5 contains the energy values of materials and organic compounds from agricultural residues.

The calorific power of the organic compound was measured in a calorimeter.

The average energy aggregated to fungicides, herbicides and insecticides applied to the mountain coffee productive system is presented in Table 6.

The summary of the demands and energy balances observed in the plots of a mountain coffee production system, considering the two phenological years analyzed, can be observed in Tables 7 and 8.

It was observed that most energy embodied in the process is solar radiation, which is 98% of the total, followed of the application of organic fertilizer.

The application of organic fertilizer is considered an important practice, not only because it replenishes the elements extracted from the soil, but also because it helps in the treatment of residues of the coffee itself.

The average energy consumption in the first phenological year 2003/2004 rated the mountain coffee plantations in the Zona da Mata region of Minas Gerais was 23,035,733.80 MJ ha^{-1}. In the second year phenological 2004/2005 was 24,918,830.18 MJ ha^{-1}.

The ratio of energy use by coffee plants is contained in Tables 9 and 10.

The radiation balance ranged between 98.98 and 99.03%, accounting for the higher energy consumption. The radiation balance of coffee plantations intercropped with other crops coffee is approximately 53% [14]. Therefore, the radiation balance is great in a coffee plantation without the consortium of another culture.

The list of energy use by plants of coffee is presented in Tables 9 and 10, in which low energy use can be observed, mainly in relation to fruits. It is possible to see that, from the total energy provided to plants, the highest use occurred in the root and the lowest, in the fruits.

4. Conclusions

Although the quantity of aggregated energy in the energy balance has been little used by plants (less than 0,3%) and their individual components, it concludes that:

1. The energy balance at the production, harvest and post-harvest can be considered positive. The evaluated systems can be considered sustainable from an energy standpoint.

2. Can say that agricultural technology has been applied to the systems efficient in terms of conversion and energy balance.
3. Organic manure is rich in nitrogen and total potassium content, therefore it is an alternative to the traditional complementary fertilization.

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